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Costs and Benefits of Smart Grids and Accumulation in Czech Distribution System

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Abstract

In our opinion, this public debate about Smart Grids (SG) ignores some important aspects of its real implementation. The most important aspect is realistic cost benefit analysis (CBA) which can be seen as a correct methodology for investment efficiency valuation. Our proposed methodology for CBA for SG implementation is mentioned and discussed in this paper. According to our research involvement of brand new customer tariffs show up to be necessary inputs for CBA. It is truth that some pilot projects for mapping of particular technical devices are today in experimental operation. These projects does not use any cpecial smart tariff, which is according to us also incorrect. In other words pilot projects which are operated regardless to the market conditions and smart tariffs are therefore incomplete and not viable. In more detail our paper collects basic information about costs and benefits of SG implementation and these information are utilized by the means of our systematic approach. The SG implementation process is explained by our methodology as a system with feedback. Finally the proposed methodology is applied and proven on a specific case of electricity accumulation in the environment of Czech Republic.

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Keywords: Advanced metering, regulation, smart grid, smart farrif, system approach

1. Introduction

The background of our analysis is set by situation in the power industry that differs a lot from other industries. It is mostly by duality of this industry which consist of regulated and liberalized part. Therefore final electricity price for customers consists also from two parts. One part is set by competition on liberalized market; the second part as a majority of the price is set by regulation authority, because of costs originates in regulated sectors (e.g. transmission system operator - TSO, distribution system

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operator - DSO, support of renewable resources - RES-E, etc…).

The philosophy of our proposed analysis is based on presumption that each impact (regardless of the fact that influences directly the customer or other market participant) represents finally benefit or cost for customer. This idea is based on the fact that the customer is the final market participant who pays for not only market, but also regulated part of electricity price.

Basis for our methodology is represented by common Net Present Value (NPV) theory. We propose to calculate balance between future discounted costs and benefits. In more detail the costs and benefits are influenced by each other as a manifestation of feedback which is involved in methodology.

2. Aspects that Influence SG Implementation

In fact, SG concept represents a change of today's energy industry system. Therefore calculation of any effectiveness must represent a calculation of differences between today's system and future energy industry system incorporating the SG concept.

2.1. Economic Effectiveness

Economical effectiveness represents basically advisability of some investment. In the most trivial case it represents calculation (balance of future cost and benefits) with regard to the time value of money – e.g. by NPV method [1].

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t} \tag{1}$$

NPV is net present value of some investment, CFt is cash flow in some year t, r is discount (time value of money) and T is lifetime of particular investment.

Refer to (1) the future CF is the most important aspect of the economic effectiveness. Therefore calculation of future CF represents the most important aspect of SG implementation. Such calculation would be utilized only by correct estimation of future cash costs and benefits regarding the evolution and liberalization of electricity market.

2.2. Electricity Market Structure

Every brand new methodology applied in the power industry must be formulated regarding to special conditions of this industry. Power industry was only partly liberalized. The endeavor of unbundling principle is to establish liberalized market optimization into the electricity market; however this market represents only a part of the power industry.

Regulated are mostly the grid sectors (transmission and distribution) and generation of electricity in RES-E. Such these sectors are either not competitive with classical technologies or investment spend for establishment of concurrent environment would be too high.

2.3. Liberalized Market Sector

Generation, consumption and trading are sectors that are fully liberalized. The possibility of access to the grid (for both generators and consumers) should be free and therefore it is possible co establish in these sectors competition. The same situation is with electricity trading, because electricity as a commodity takes place on free markets (exchanges or OTC).

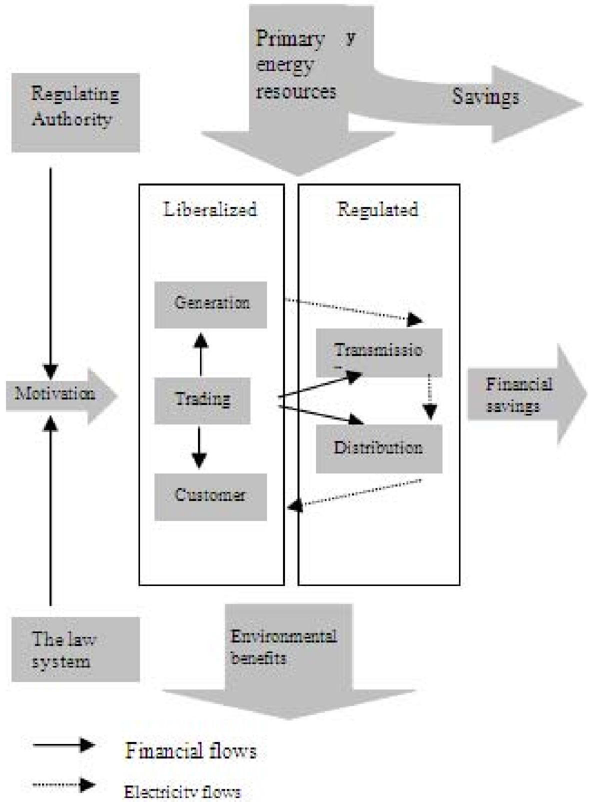

Fig. 1. Structure of the electric power sector with connections between particular market segments

Liberalization is opportunity for competition. On the other hand according to [2] the liberalization could result in avoiding of capital-intensive technologies with long construction and life times. This phenomenon became more visible in despite of their obviously low marginal costs. Because of risk avoidance, short time horizons are preferred.

2.4. Regulated Market Sector

It is of course not economical to build another concurrent grid to establish some competition in the sector of grids operators. Therefore some regulation (made by state authority) in this sector are reasonable. The only way how to establish concurrence in electricity delivery is the use of natural gas in Combined Heat and Power (CHP) devices or usage of batteries. Such devices could on condition of SG implementation displace necessity of electricity transport.

Another part of this regulation is also support of “natural friendly” technologies e.g. renewables (RES-E) that are not able to compete with classical technologies. The theoretical basis for this support is in theory of externalities which exceeds framework of this paper. More information in [6].

3. The System Approach for CBA

The infrastructure of subjects involved into SG can be seen as a system. In general the whole Power Industry can be seen as environment of SG system. The development and outputs of the SG system are characterized by their inputs. In the first resolution, the trivial schema is system is on Fig. 2.

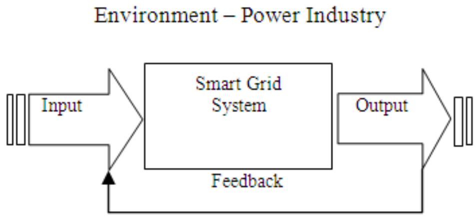

Fig. 2. System in the first resolution

The more detailed resolution will divide one black box from figure 2 to more partial systems (subsystems). According to this philosophy, SG is subsystem of the whole Power Industry and power industry is an environment for SG.

3.1. Transformation of Inputs

Every system transforms inputs into outputs. The process of transformation can be described by (2).

$$O(t) = T[I(t), S(t)] \tag{2}$$

O represents vector of outputs/responses of the system, I represents vector of inputs, S represents vector of State variables and operator T represents transformation process.

Vector of state variables characterizes the system and represents borders for the process of transformation which is represented by operator T.

According to above mentioned analysis we are now able to describe the particular costs and benefits that represent inputs and outputs of SG implementation.

3.2. Inputs into SG System

Threshold investment into SG infrastructure I_0: The largest value of investment will be spent on Advanced Metering Management (AMM) devices development, installation (incl. eventual reconstruction of electricity distribution in the house etc…) and introduction into operation. Related are investments into communication and measuring system, or SG management and administrative SG departments of Distribution System Operators (DSO).

Interim investment into state of the art maintenance of SG system. I_I: It is pretty clear that future moral maintenance of the SG system will need lots of capital expenses. The maintenance investment means not repairs, but future investment into most developed technologies that would be available to keep the AMM system modern and up-to-date.

Investment into foundation of marketing commu- nication and market share possession I_M: Represents investment for AMM producers. They represent investment connected with market penetration, marketing or communication.

Capital costs that originate from selected methods of financing. C_C: Capital costs connected with financing of AMM devices implementation. These costs mostly represent time value of external capital, risk bonus connected with margin of the lender.

$$C_{ct} = LC(t)_t \cdot (i_{it} + rm)\ . \tag{3}$$

$LC(t)_t$ represents residue of external capital (principal) in the year t which is time variable, i_{it} is inter-bank interest (mostly EURIBOR) in the year t and rm is risk margin which contains risk bonus and margin for the lender.

Maintenance costs of AMM devices CM: Means replacement of spare parts, costs for repairs, long term service costs, wear and tear etc…

3.3. Outputs/Responses from SG System

Benefits of increased price of energy produced in RES-E B_{RES-E}: Is higher price of electricity that has for today's market low price because of its unreliability and long term unpredictability. For smart customers such electricity would have higher price because of possible time shifting and demand response.

Decrease of necessary amount of grid regulation service B_{REG}: Today's situation needs lots of regulation to keep the transmission and distribution system stable.

Benefit of electromobility utilization B_{MOB}: Electromobiles or hybrid cars represent real option (alternative) to classical today's cars. SG implementation would be needed if electro mobility would spread between customers in the market.

Benefit of various consumption monitoring $B_{integration}$: Future integration of monitoring of various commodities (e.g. electricity, gas, heat or water) consumption. This monitoring would safe personal costs and also non technical losses (stole electricity).

Benefit of mutual concurrence between various energy commodities $B_{concurrence}$: Integrated measuring would utilize concurrence between energy commodities, e.g. electricity, gas or heat. By the consumers the various kinds of energy convertors would be installed. Such devices would utilize concurrence between e.g. electricity and gas, because gas can be transformed by the engine (Combined Heat and Power - CHP) into electricity (with by-product heat). Under some market conditions this could be beneficial.

Benefit of cross-border monitoring $B_{Monitor}$: Better monitoring of cross-border flows after implementation of high-voltage SG would be able to replace today's not so far successful Flow-Based Allocation (FBA) model.

Implementation of brand new intra day price changes that would motivate the customer (e.g. demand response, load shifting). B_{Market}: Such an intraday price changes connected with automatic load shifting represent opportunity for traders to construct brand new products according to their actual portfolio and for customer to minimize costs paid for electricity. Avoiding of consumption during peak hours represents savings for customers.

Avoidance of future investment cost into trans- mission and distribution grid infrastructure, necessary without SG concept. $B_{Inv.D/TSO}$: Future development and maintenance of grids would not be possible without massive investment, especially under condition of future growth of electricity consumption (connected with economical growth).

Benefit of accumulation utilization B_{acc}: SG would be necessary for effective way of accumulation implement-tation.

3.4. Internal Features of the SG System

The SG represents not only brand new system of regulation, but also brand new infrastructure. This infrastructure – Advanced Metering Management (AMM) is sum of intelligent devices which are able to communicate both directions (from customer to distribution grid/trader and vice versa). The most important motivation for its implementation would be in the near future savings originates from lots of aspects, e.g. impossibility of electricity storage, losses in the grids during transport of electricity (about 7%), possibility of decentralized RES-E or electro mobiles spread etc.

The most visible problem that remains during today's development of AMM devices is a digital noise from the grid, especially from low voltage (retail) part of the grid.

3.5. System Environment – Energy Industry

The environment is the power industry which represents strategic industry for each country. It directly influences not only nature environment, our global resources of fossil and other fuels, but also the economical growth.

The environment for SG implementation is the power energy sector. The most important for SG implementation is not only the described market structure, but also the legislation that establishes environment for utilization of market participant's motivation. Therefore it has direct impact on the feedback in our chosen analogy with negative – feedback stabilized system. Therefore more is written in chapter 4.5.

3.6. Feedback - Motivation/Stimulation in the Power Industry

It is truth, that today's power industry sets some kind of borders for any investment activity. The investors need economic stimulation to be motivated for such activity. This stimulation is represented mostly by incentives. The spread of AMM will represent opportunity e.g. Energy portSM (more in [3]) represent high potential for unification.

3.6.1. Market Stimulation Incentives

Trader has to be involved into the practical operation of SG. Only trader could be the real actuating unit that will enable the market stimulation process.

The structure of electricity price, which is set from the side of trader to the customer, will represent the final crucial point of SG implementation. The price and amount of electricity, available on the market, depends on fact which kind of resource will be during peak hours the marginal one. If it is a plant with high operation costs (e.g. CCGT unit) the price would be high and every saving will be important stimulus for SG effectiveness. On the other hand marginal plant with low operation costs causes very low stimulus.

3.6.2. Regulatory Stimulation Incentives

Regulatory stimulation can be e.g. obligation to customers to install AMM system. The purchase costs can be spent by distribution system operators but it will definitely be paid from budget that is collected from all electricity customers. Such repayment would be guaranteed by state.

Customers would be afterwards indemnified by the fact that AMM will enable savings in annual electricity costs regarding to new smart tariffs.

4. Valuation of Particular Costs and Benefits

This paper has described the systematic approach to SG implementation problem and has mentioned a few instruments for suitable financing methods.

The systematic approach identifies necessary inputs, outputs and aspects of the system environment and feedback aspects. Such description will be necessary for the cost benefit analysis which should be according to my opinion the most important criterion for valuation if SG could be effective concept or not. The very first and easy approach is cost benefit analysis from the consumer's point of view.

$$\sum_{t=0}^{T}\frac{I_t}{\left(1+r\right)^t}+\sum_{t=0}^{T}\frac{C_t}{\left(1+r\right)^t}=\sum_{t=0}^{T}\frac{B_t}{\left(1+r\right)^t}\,. \tag{4}$$

I_t is particular kind of investment cost, C_t is particular kind of operational cost, B_t represents particular benefit, r represents discount and T lifetime of SG infrastructure.

This approach represents one possible way for SG effectiveness evaluation. The variables in (4) are defined by inputs, outputs and also feedback of the system approach proposed above. The most important problem is therefore connected with data obtaining for (4). The authors of this article are in the beginning of the research and final achievement should be methodology that would be suitable for valuation of SG implementation valuation. For better imagination, the case study from the area of Czech Republic follows.

5. Case Study

For our experimental approach we have chosen common household house (with approx. 10 flats) in the Czech Republic. The case study reflects conditions (e.g. electricity prices, household consumption, PV production etc.) in the Czech Republic. This case study would suppose smart usage of electricity accumulation, which is one of most visible benefit mentioned in (4). It is obvious that without AMM such smart accumulation would not be possible.

We suppose more household house with common consumption of electricity without smart cogeneration (decentralized combined heat and power unit). Additionally we suppose two ways of smart behavior of such household.

Table 1. Benefits (summer 2Q and 3Q) per 1 year

Description	Profit €/MWh	Cycles	Profit €/ year
Load leveling(to enable supply for own consumption)+crowding out of peak consumption	23	4000(180 per year)	623,98
Timeshifting of produced electricity from PV plant	9		77,65
Off-peak timeshifting	14		22,68

Table 2. Benefits (winter 1Q and 4Q) per 1 year

Description	Profit €/MWh	Cycles	Profit €/ year
Load leveling(to enable supply for own consumption)+crowding out of peak consumption	23	4000(180 per year)	249,59
Timeshifting of produced electricity from PV plant	Not available due to higher consumption(load) than PV plant production		
Off-peak timeshifting	14	4000(180 per year)	120, 96

The main issue regarding smart-grid system based on implementation of PV plant and accumulation is to correctly evaluate expectations of future development of electricity prices. The key driver is the development of spreads between the off-peak load, peak load and the real value of electricity PV plant production diagram, yearly based (considering 41€ in case study). The PV production in 1stand 4thquarter [8] is 40% of production in 2ndand 3rdquarter. Consumption of house is 170kWh in

(1st,4thquarter) 204kWh (2ndand 3rdquarter). Prices of electricity (smart tariffs) are presumed as follows: Baseload (0-24) 57 EUR/MWh, Peakload (8-20) 64 EUR/MWh Offpeak (0-8 and 20-24) 50 EUR/MWh. Finally the battery indicative price is 150 EUR/kWh

Table 1 and 2 represent the evaluation of economic benefits divided to two periods, summer characterized by evaluation of peak production of PV plant and winter characterized by higher consumption and lower production of electricity.

Table 3 shows us result of valuation of the SG system with the implemented smart-metering and accumulation. We were working with the reasonable discount rate of 8% due to non extremely risk connected with the investing to the accumulation and devices responsible for smart behaving of the unit. The negative result of net present value indicates a non-effective solution of an investment. However, calculation mentioned above is based on cash flow of benefits from spreads between off-peak load and peakload and the crowding out effect considering power production from the PV plant.

We have to incorporate 3 types of economic benefits:

• Load leveling effect is based on feature of battery to hold the consumption as a reliable source of electricity. This effect leads to the crowding out of consuming peakload electricity consumed with the electricity produced in PV plant.

• Timeshifting effect is based on the accumulating surplus power during peak of the PV plant production (the excess of PV plant production above the consumption) and supporting the delivery of electricity accumulated during the decrease of the PV plant production bellow level of consumption.

Table 3. Total economical analysis

NPV for 20 y lifetime		Cathegory	Result [EUR]
Anuity	9,81815	Income 1Y	1 094,85
Lifetime	20	Outlay year 0 (investment)	11 664,00
Discount	8 %	NPV	- 914,57

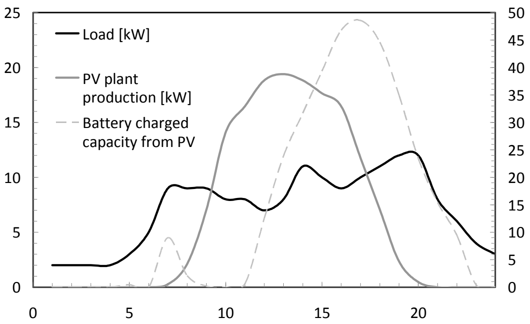

Fig. 3. Battery charging during 1st and 4th quarter utilizing PV.

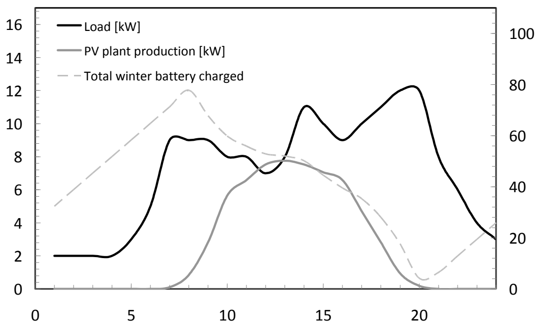

Fig. 4. Battery charging during 2nd and 3rd quarter utilizing both PV and off peak charging

• Off-peak timeshifting effect is marginal activity based on accumulating of off-peak load and shifting this energy to peakload hours. Due to our conservative approach we consider this effect only marginally and don´t support speculative aim to benefit mainly from spread between peakload and off-peak load.

The first peak of battery charged capacity from PV in Fig. 3 is caused by fact that before 8 AM it seems to be more convenient to store electricity from PV and spend directly electricity from the grid at the off-peak prices.

6. Conclusions

It is obvious that necessity of SG implementation will grow with increasing amount of decentralized RES-E. Under this condition the spread between low and high price will be much higher than today and will lead to reasonable accumulation and mainly to smart grid concept implementation. Low price would occur during maximal generation in RES-E and vice versa.

The information mining is not an easy mission. Therefore we have chosen example with well known features. But our theoretical system approach for CBA can be used for much more complex applications. Finally we believe that such approach will be useful as a methodology for smart grid costs and benefits valuation.

It is pretty interesting that in Czech Republic remote control of demand exists for more than 30 years. We can call it 0th step of SG implementation. The device in the distribution grid which serves as transmitter transmits (under condition of surplus of electricity in the grid) impulse which is recognized in the consumption device. Such impulse switches accumulating heating. Similar impulse turns these devices off (when addition consumption is not needed). Disadvantage of this system is only one-way communication and especially this fact that it is not ready for accumulation and RES-E.

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